PESTICIDES—

A study of their effects on the growth and transpiration of cucumber, tomato, and potato plants . . . .

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THE INFLUENCE OF VARIOUS PESTICIDES ON THE GROWTH AND TRANSPIRATION OF CUCUMBER, TOMATO, AND POTATO PLANTS

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INTRODUCTION

Many of the materials developed for possible use in the control of insects and diseases on vegetable crops are toxic in some degree to the host plants (1, 2). In fact, many of the most promising in preliminary tests finally have to be discarded because they prove to be too injurious when tested in the field. Others, of which DDT is an example, cause little or no injury on one host (potato) but should not be used on another (for instance certain varieties of squash and cucumber). Since some of the many new organic pesticides developed during the past two or three years were known from field experiments to be more or less phytotoxic, it was decided to study their effect also on various plants grown in the greenhouse. The results obtained in a number of field and greenhouse tests are discussed in the text which follows.

FIELD EXPERIMENTS ON CUCUMBERS

In the summer of 1945, DDT was used with several fungicides in formulations to control cucumber insects and diseases. These were applied to cucumbers of two varieties (National and Ohio 31). The Ohio 31 plants treated with formulas that contained DDT (technical grade with set point of 89° C) were immediately and drastically affected, and as a result most of them were not

TABLE 1.—Effect of different formulations of DDT applied at different concentrations of spray and dust on the growth of Ohio 31 cucumbers in the field.

Formulation and form of application	Height of plant (inches) Pounds active in 100 gallons		
DDT as spray	1	½	¼
1	2.6	4.1	7.7
2	3.6	5.9	7.9
3	5.6	8.1	12.1
	Percent active ingredient		
DDT as dust	4	2	1
1	4.0	5.4	8.8
2	5.0	6.5	10.5
3	6.6	11.1	13.0
Average of sprays	3.9	6.0	9.2
Average of dusts	5.5	7.7	10.8
Derris Root			
Spray 4-100 of 5% rotenone	....	15.2	....
Dust 15-85 of 5% rotenone	....	15.3	....

over 6 inches high when those treated with a formula like COC-S plus derris were 24 to 30 inches long. The National variety was much less affected. It was suggested that the formulation of the DDT concentrate might be in some way connected with the injury that appeared, since numerous mixtures had shown some variations in phytotoxicity to other hosts. With this in mind a later planting of Ohio 31 was treated with DDT prepared by three different manufacturers. These formulations as supplied by different manufacturers were applied as sprays and dusts and in three different degrees of dilution. The results are shown in table 1.

Formulation number 1 was more phytotoxic than numbers 2 and 3 at all dilutions of both sprays and dusts. All sprays caused more stunting than their corresponding dusts. This was not true of the rotenone-bearing derris root applications, and these were less phytotoxic than any of the DDT preparations.

GREENHOUSE EXPERIMENTS ON VARIOUS PLANTS

In the fall of 1945 various experiments were started in the greenhouse where cucumbers, tomatoes, and potatoes were sprayed with a variety of fungicidal and insecticidal materials to determine their effect on growth and rate of water loss. In a preliminary test of the influence of DDT on the growth of cucumbers, a technical grade of DDT was processed in three lots in a hammermill. One contained 50 percent of EM 23 talc, one contained 50 percent of Cherokee clay, and the other 50 percent of bentonite. These were then formulated at one pound of the mixture in 100 gallons of water and applied three times at 5-day intervals. At the end of 3 weeks the average plant heights for the different treatments were 6.4, 4.2, 3.6, and 3.4 inches for plants with no treatment, talc, clay, and bentonite compositions, respectively.

In another experiment cucumber plants were treated with Zerlate, COC-S, Methoxy, Rhothane, DDT, JP 70, Deenol, and symmetrical hexachlorocyclohexane, which will be referred to in this article as HCCH. The average plant height at the end of 3 weeks was 5.0, 5.0, 4.7, 4.0, 3.5, 1.8, 1.6, and 1.5 inches, respectively. These data indicated that some of these new insecticidal preparations could be expected to affect the growth of cucumbers unfavorably. Methoxy and Rhothane are chemical relatives of DDT. JP 70 is a water miscible spray concentrate which contains 70 percent by weight of DDT isomers and chlorinated polymers. It has been used to spray potatoes for the control of both leafhoppers and aphids. Deenol, which is an emulsified oil containing 25 percent of DDT, is not recommended for use on plants but has been used to spray potatoes in the same manner as JP 70.

The effect of some of the insecticides listed in the previous paragraph on the growth of cucumbers in this experiment is shown in the two photographs of figure 1. In the upper section the treatments from left to right are: no treatment, Methoxy, Rhothane, and DDT. In the lower section they are: no treatment, DDT, JP 70, and HCCH. The leaves on the plants treated with DDT are very crinkled and cupped and somewhat chlorotic on the margins. The plants treated with JP 70 are weak and many have collapsed. HCCH caused a severe chlorosis of the leaves as may be seen from their white appearance in the photograph, and many of them are dead.

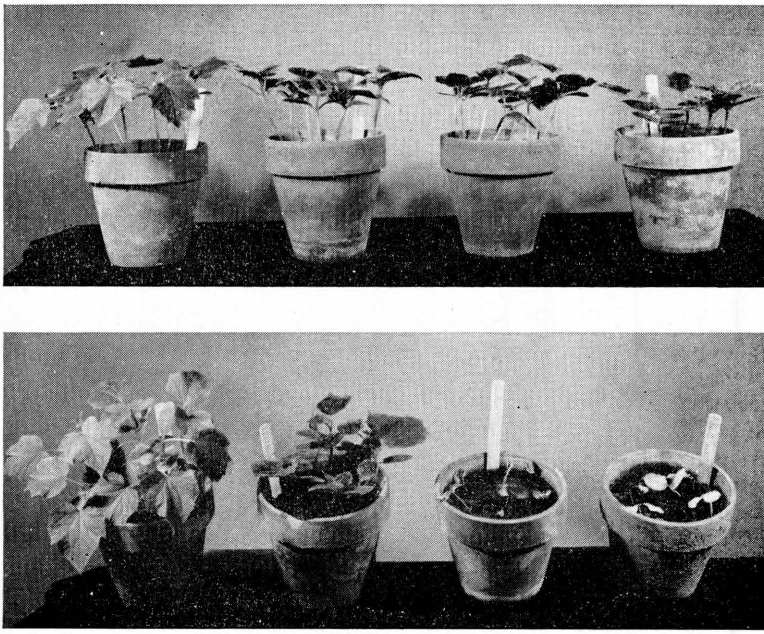

Fig. 1.—Effect of various organic insecticides on the growth of cucumbers (See text for order of treatments).

Various concentrations of DDT were applied to three cucurbits; the results are given in table 2.

Muskmelon was more severely stunted than cucumber or watermelon. The concentration of ⅛-100 caused some stunting of muskmelon and watermelon but seemed to have little effect on the growth of cucumber.

TABLE 2.—The influence of various concentrations of DDT on the growth of three cucurbits. These were sprayed 5 times at 4-day intervals.

Concentration of DDT (50% active)	Cucumber		Muskmelon		Watermelon	
	Average height in inches	Weight of 20 plants in grams	Average height in inches	Weight of 20 plants in grams	Average height in inches	Weight of 20 plants in grams
1 -100	2.70	54	2.76	37	5.25	63
½-100	3.50	72	3.73	58	6.06	73
¼-100	3.90	76	4.65	70	6.75	75
⅛-100	4.60	100	5.98	74	8.40	78
No treatment	4.55	92	8.07	81	10.17	81

In another experiment five cucurbits were sprayed five times at 5-day intervals with four of the new organic insecticides. The results are given in table 3. Hexachlorocyclohexane (HCCH) and JP 70 were more injurious than DDT and Rhothane (DDD). Watermelon was injured more severely than any of the other cucurbits included in this list.

TABLE 3.—Influence of four organic insecticides on the growth of various cucurbits. Sprayed 5 times at 5-day intervals.

Treatments	Cucumber		Muskmelon		Squash		Pumpkin		Watermelon	
	Ht. in inches	Wt. in grams	Ht. in inches	Wt. in grams	Ht. in inches	Wt. in grams	Ht. in inches	Wt. in grams	Ht. in inches	Wt. in grams
DDT (50%) 1-100	2.9	16	2.1	9	3.0	24	5.7	44	3.5	19
Rhothane (50%) 1-100	2.6	13	1.7	5	3.0	26	6.4	57	2.5	14 SI
HCCH (6%) 2-100	Dead		1.3	4 SI	4.1	35	6.6	51	Dead	
JP 70 1-100	1.2	10 SI	1.3	5MI	2.0	20 SI	Dead		Dead	
No treatment	3.3	19	1.7	6	4.5	41	6.5	55	3.3	20

SI=Severe injury. MI=Moderate injury.

Since different formulations of DDT had shown such a wide variation in injury to the host plant, it was decided to compare a series of hexachlorocyclohexane preparations of which several were available. These were all prepared to contain approximately two ounces of the gamma isomer of HCCH in 100 gallons of spray material. The injury caused by formulations prepared by six different manufacturers ranged all the way from slight stunting and slight chlorosis to the death of cucumber seedlings.

For most samples the injury was less, however, than that caused by 1 pound DDT (50%) in 100 gallons. Only one of the four formulations caused any marked injury to young tomato plants. This one injured the growing points of the tomatoes which injury was followed by severe deformation of the stem and leaves. DDT at 1-100 of 50 percent material was just as injurious (chlorosis, necrosis, and deformation of the leaves) in the same experiment.

Corn

DDT, which is now used to a considerable extent for the control of corn borer on sweet corn and on field corn grown for seed, was applied in four concentrations to corn seedlings. The results, together with others for HCCH, Rhothane, and Methoxy are given in table 4. None of the treated seedlings grew quite as vigorously as the untreated checks, but none of the treatments caused any marked injury except HCCH and DDT at 4-100. This concentration of DDT caused some stunting and many of the leaf tips were killed back for a distance of one or two inches. The HCCH seemed to have a weakening effect on the mid-ribs of the leaves so that many of them broke over from their own weight.

TABLE 4.—Influence of organic insecticides on the growth of corn seedlings. Sprayed 7 times at 4-day intervals.

Concentration of treatment	Average height of plants in inches	Average weight of plants in grams	Notes on injury
DDT (50%) 4-100	9.6	6.2	Leaf tips brown.
2-100	10.5	6.5	Slight browning of tips.
1-100	11.0	6.8	Very slight browning of tips.
½-100	11.3	7.0	Normal.
HCCH (5%) 2-100	10.1	6.0	Leaves broken at midrib.
Rhothane (50%) 2-100	11.4	7.1	Normal.
Methoxy (25%) 4-100	11.1	6.5	Normal.
No treatment	12.0	8.0	....

Cucumber

In another experiment many of the insecticides that might be used on cucumbers for the control of cucumber beetle or of cotton aphids were applied to cucumbers grown in the greenhouse in April. The data are given in table 5, where the growth of differently treated plants is compared with those of the untreated check, when the average size of these check plants is taken as 100. Nearly all of the materials tested caused some stunting, but this effect was most noticeable among the synthetic organics, especially DDT and related materials. Talc, clay, and bentonite as conditioners of DDT again stunted in that order, but talc would have caused less injury than clay or bentonite had these materials been applied alone (1).

TABLE 5.—Influence of various insecticides on the growth of cucumbers. Data given as percentage of growth of untreated and treated plants when their size=100. Sprayed 4 times at 4-day intervals.

Treatments	Weight of 20 plants	Height of plants	Width of 2nd true leaf
No treatment	100	100	100
Sabacide 4-100	102	109	101
Ryanex 4-100	94	101	104
Pyrocide 1¼-100	87	96	98
Kryocide 2-100	86	97	100
Derris (5%) 4-100	86	96	97
Methoxy (25%) 2-100	85	86	108
DDT (50%) 1-100	82	74	65
Evergreen 1-100	80	88	102
DDT (25%) 2-100	78	63	60
JP 70 ¾-100	73	68	55
Calcium arsenate 4-100	72	84	97
HCCH (6%) 2-100	70	77	75
DDT in talc (50%) 1-100	68	73	55
DDT in clay (50%) 1-100	67	68	53
Rhothane (50%) 1-100	67	61	66
DDT in bent. (50%) 1-100	63	56	56

The comparative effect of various fungicides and insecticides on the growth of cucumbers was studied in another experiment, the results of which are shown in table 6. Bordeaux was one of the most injurious of the fungicides and, among the insecticides DDT again caused the maximum stunting. The addition of either Kryocide (a natural cryolite) or DDT to COC-S increased the stunting effect of this fixed copper. The cryolites (Kryocide, Alorco, and Dutox) were less injurious than DDT or its chemical relatives.

In still another experiment cucumbers were sprayed with a series of fungicides to determine the influence of these materials on growth. As a group, the carbamates were less injurious than either fixed coppers or Bordeaux. Dithane caused considerable stunting in this experiment, as well as in some others. The quinolinolates and zinc mercaptobenzothiozole caused only minor stunting. Manganese ethylene bis dithiocarbamate was more injurious than the zinc form, as was the case during the summer in various field tests.

Varietal Response of Cucumbers

The effect of various insecticides on the growth of eight varieties of cucumbers was studied in another experiment, since earlier tests had indicated that all varieties were not equally affected by these materials, especially DDT. Four test materials, namely derris root (5% rotenone) 4-100, DDT 1-100,

TABLE 6.—Comparative stunting of cucumbers by various fungicides and insecticides. Sprayed 5 times at 5-day intervals.

Treatments	Formulas	Av. ht. of plants in inches	Weight of 20 plants in grams	Notes on injury
No treatment	....	4.85	66	Normal.
Derris (5% rotenone)	4-100	5.30	74	Normal.
Zerlate	2-100	5.10	73	Normal.
COC-S	3-100	5.00	72	Normal.
Kryocide	2-100	4.75	68	Normal.
Mn 8 quinolinolate	1½-100	4.75	66	Normal.
Alorco	2-100	4.65	66	Normal.
Tribasic	2-100	4.60	64	Normal.
Dutox	2-100	4.60	62	Nearly normal.
Cu 8 quinolinolate	1-100	4.40	60	Normal.
Fermate	2-100	4.40	58	Slight stunting.
COC-S + Kryocide	2-2-100	4.35	64	Nearly normal.
Methoxy (25%)	2-100	4.00	60	Slight stunting.
Bordeaux	4-4-100	3.50	40	Medium stunting—cupped leaves.
Rhothane	1-100	3.00	40	Medium stunting—mottled leaves.
HCCH (6%)	2-100	2.80	30	Medium stunting - chlorotic leaves.
DDT (50%)	1-100	2.60	36	Severe stunting—crinkly leaves.
COC-S + DDT	2-1-100	2.30	30	Severe stunting—crinkly leaves.
JP 70	¾-100	2.00	18	Severe stunting—drooping leaves.
Dithane D-14	3-100	2.00	12	Very severe stunting—holes in leaves.

TABLE 7.—Comparative stunting of cucumbers by various organic and inorganic fungicides. Sprayed 4 times at 5-day intervals.

Treatments*	Average height of plants in inches	Weight of 20 plants in grams
Zerlate 1½-100	5.4	59
Fermate 1½-100	5.3	56
Zinc bis† 1½-100	5.3	55
Cu 8 quinolinolate 1-100	5.2	54
COC-S 2-100	4.9	44
Copper A 2¼-100	4.8	47
ZMBT‡ 1-100	4.6	55
Mn 8 quinolinolate 1-100	4.5	47
Tribasic 2-100	4.4	42
Manganese bis§ 1½-100	4.4	38
Bordeaux 4-4-100	3.8	37
Dithane + $ZnSO_4$ + lime 4-1-½-100	3.3	33
No treatment	5.0	55

*Slight marginal injury with Bordeaux and Manganese bis. Moderate injury with Dithane.
†Zinc ethylene bisdithiocarbamate.
‡Zinc mercapto benzothiozole.
§Manganese ethylene bisdithiocarbamate.

HCCH 1-100, and JP 70 1-100, were compared on National, Early Fortune, Straight 8, Stays Green, Ohio 31, Arlington White Spine, Davis Perfect, and Deltus. When the effect of all four treatments was averaged the varieties were stunted in the order named with National showing the least and Deltus the most. When the effect of each treatment was averaged for all eight varieties JP 70 proved to be the most injurious, followed in decreasing order by HCCH, DDT, and derris (rotenone). The plants treated with rotenone were as large as the check series and appeared not to have been injured. Injury to most varieties was severe by JP 70 and HCCH and moderate by DDT.

In another larger experiment, 49 varieties of cucumbers were treated with four concentrations of DDT in an effort to classify them on the basis of susceptibility to injury and if possible to discover what concentration of DDT the different varieties might be able to withstand without appreciable injury. The data relative to this experiment will be reported elsewhere, but the average effect of the different concentrations of DDT on all varieties is shown in figure 2.

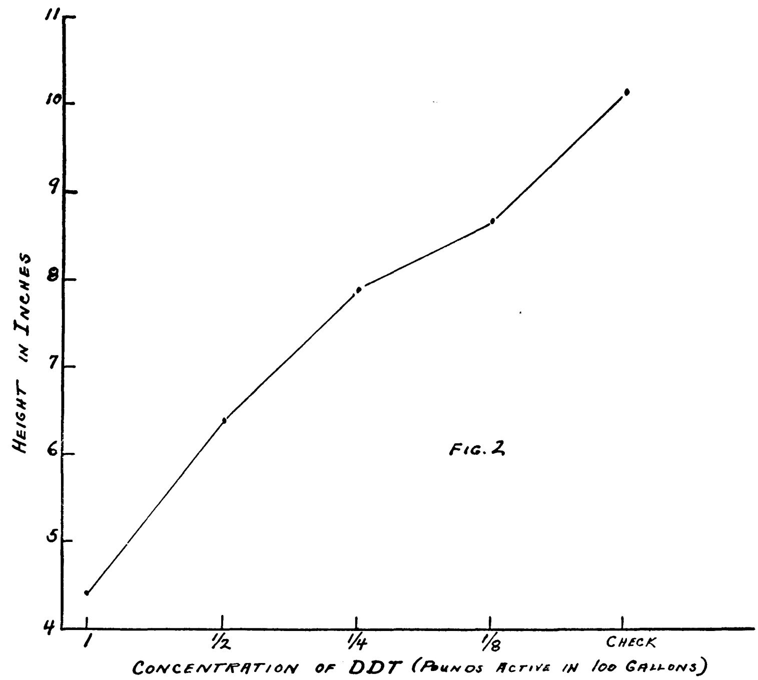

Fig. 2.—Average growth in height of 40 varieties of cucumbers treated with different concentrations of DDT.

The stunting caused by ⅛ pound of DDT in 100 gallons progressed in a nearly straight-line relationship with each successive doubling of the quantity of DDT in 100 gallons of spray material.

Tomato and Potato

Most of the materials used in the phytotoxicity studies on cucumbers were also used on tomatoes and potatoes. The data relative to one series are given in table 8. Both insecticides and fungicides were included in this experiment. The insecticides as a group were more injurious to tomatoes than the fungicides. DDT caused considerable chlorosis and some leaf deformation when used in excess of the 1-100 concentration. Methoxy seemed to cause the tomato leaves to develop very much as they do when affected with shoestring mosaic. Rhothane caused a type of injury similar to that of DDT, but was somewhat less severe at comparable concentrations. JP 70, which contains isomers of DDT solubilized in an oil vehicle, is quite toxic to tomatoes. Dithane D-14 without the addition of zinc sulfate and lime is quite injurious, causing necrotic spots in the leaves and a weakening of the stems.

TABLE 8.—Phytotoxicity of various insecticides and fungicides to tomatoes and potatoes grown in the greenhouse. Sprayed 5 times at 5-day intervals.

Material	Formula	Relative plant height when check = 100	Notes on injury
Tomato			
No treatment	....	100	Normal.
Copper 8 (50%)*	2-100	104	Normal.
Zinc MBT (50%)†	2-100	104	Normal.
Nickel bis‡	2-100	103	Normal.
Zinc 8 (50%)§	2-100	100	Normal.
Guantol	2-100	99	Normal.
DDT (50%)	2-100	95	Slight marginal chlorosis.
Zerlate	2-100	90	Normal.
Methoxy (50%)	2-100	87	Shoe-string effect on young leaves.
HCCH (6%)	2-100	80	Leaves crinkled with necrotic spots.
Rhothane (50%)	2-100	75	Mottled chlorosis. Purple veins.
Dithane D-14	4-100	71	Necrotic spots, stems weak.
DDT (50%)	8-100	64	Severe deformation and chlorosis.
JP 70	2-100	56	Severe malformation, chlorosis, and defoliation.
Potato			
No treatment	....	100	Normal.
Zerlate	2-100	122	Normal.
Zinc MBT (50%)†	2-100	122	Stems somewhat weak.
Dithane D-14	4-100	111	Necrotic spots stems weak-columnar.
Copper 8 (50%)*	2-100	106	Slight chlorosis—columnar growth.
Zinc 8 (50%)§	2-100	100	Normal.
DDT (50%)	2-100	100	Normal.
Methoxy (50%)	2-100	100	Slight marginal chlorosis.
JP 70	2-100	100	Leaves small and chlorotic. Columnar growth.
Guantol	2-100	94	Normal.
Rhothane (50%)	2-100	94	Slight chlorosis.
Nickel bis†	2-100	90	Slight chlorosis.
DDT (50%)	8-100	90	Mottled chlorosis. Columnar growth.
HCCH (6%)	2-100	72	Considerable chlorosis.

*=Copper 8 quinolinolate.
†=Zinc mercaptobenzothiozole.
‡=Zinc 8 quinolinolate.
§=Nickel ethylene bis dithiocarbamate.

The response of potatoes to this same group of materials was similar to that of tomatoes except that elongation of the stems was not inhibited to as great an extent. Plants that received some of the treatments were more columnar in growth than normal, since the petioles and the leaves they bore were shorter. Chlorosis of varying degrees of severity was common, as is shown by the notes on injury. The stems were also weak on many of the plants and had to be supported by bamboo sticks. Elongation was often normal or even excessive on plants that showed considerable leaf injury. DDT

TABLE 9.—Influence of various pesticides on the growth and development of tomato plants sprayed 5 times at weekly intervals. Numerical data relative to weight and height given as percentage of growth of untreated plants.

Treatments	Weight of tops	Height of plants	Plant condition
No treatment	100	100	Normal.
Cu 8 quinolinolate 1-100	109	110	Normal.
Zerlate 2-100	100	103	Normal.
COC-S 4-100	96	101	Nearly normal.
Copper Hydrate 3-100	93	96	Slight stunting.
Bordeaux 8-8-100	85	80	Slight stunting—some leaf deformation.
Dithane + $ZnSO_4$ + lime 4-1-½-100	79	61	Slight stunting—some leaf deformation.
DDT (50%) 2-100	77	53	Slight stunting—leaves mottled.
JP 70 1-100	74	45	Moderate stunting and leaf injury.
HCCH (6%) 2-100	58	23	Leaf appearance similar to severe mosaic.
Dithane D-14 4-100	47	14	Leaves severely injured, many dead.
DDT (50%) 6-100	43	10	Severe stunting and leaf discoloration.
Deenol (25%) 2-100	43	8	Severe stunting and chlorosis.

used at the rate of one pound of active ingredient in 100 gallons of water had no visible effect on growth, but some chlorosis was evident when the amount used was increased to four pounds in 100 gallons. HCCH was one of the most injurious treatments on potatoes. Dithane D-14 was somewhat less injurious to potatoes than to tomatoes.

The relative growth of tomato plants when sprayed at weekly intervals with a second series of pesticides is indicated in table 9, where the numerical data on height and weight of tops are given as percentages of the untreated check plants. Some interesting growth responses were observed and these are also recorded in the table.

The insecticides as a group were much more injurious than the fungicides, as was observed earlier on cucumbers. Dithane D-14 was the most injurious of the fungicides but it was safened greatly by the addition of zinc sulfate and hydrated lime. It is possible that this is one of the reasons that the addition of these supplementary materials often improves the performance of Dithane

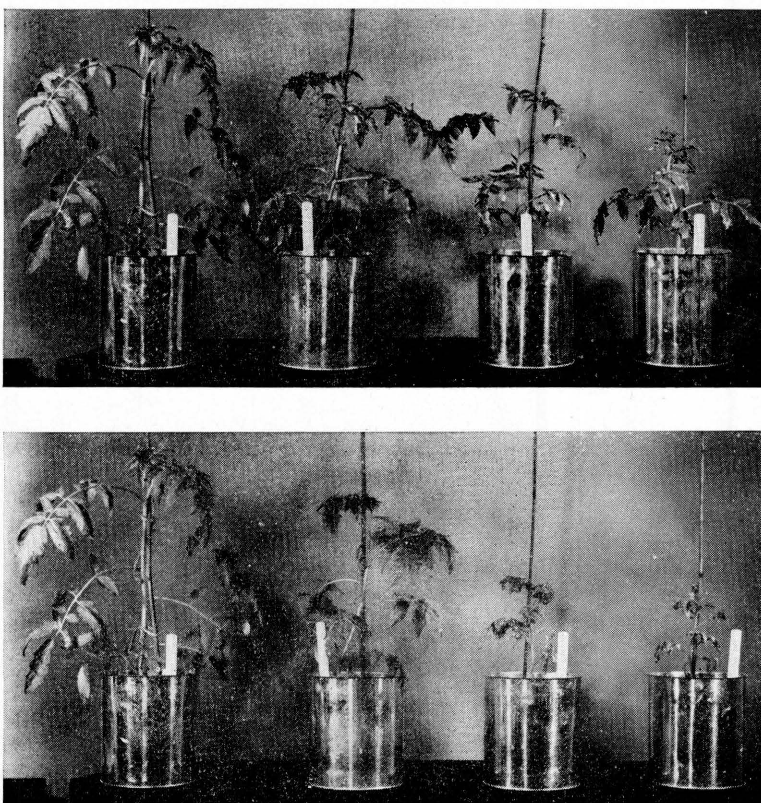

Fig. 3.—Influence of various pesticides on the growth of tomato plants. The treatments in the upper sections, left to right, are—check, DDT, JP 70, and HCCH; in lower section are—check, DDT 1-100, DDT 3-100, and Deenol.

D-14 in the field. Bordeaux mixture again caused more stunting than the fixed coppers, Zerlate, or Copper 8 quinolinolate. Plants treated with the first four compounds listed in table 9 had comparatively little effect on the growth of tomatoes in this experiment. On the other hand, all of the insecticides caused at least some injury and some of them nearly killed the plants; for instance, DDT (6-100) and Deenol. The growth response of tomatoes treated with these materials is shown in figure 3. HCCH was extremely injurious (far right in upper section of figure 3), and DDT at 3 pounds of active material in 100 gallons of water, as well as the oil-solubilized form known as Deenol, caused very severe stunting. These data indicate that neither DDT nor HCCH should be used as sprays on greenhouse tomatoes except in low concentrations (1-100 or less).

The influence of a list of materials similar to those in table 9 on the growth of potatoes is indicated in table 10. One of the most noticeable differences between the growth reactions of the two kinds of plants is their response to the applications of DDT. This material at 2-100 caused no apparent injury to potatoes and the 6-100 (3 pounds active) caused but little reduction in growth, although the leaves were smaller than those of the check plants or those treated with DDT 2-100. Dithane D-14, Bordeaux, Deenol, JP 70, and HCCH did cause stunting which was quite severe in some instances. The reduction in height of the plants frequently did not correspond to the reduction in weight, apparently due to the fact that elongation sometimes continued even though leaf size and petiole length were reduced by an injurious treatment. The weight of the fourth, fifth, and sixth leaves formed seemed to agree more closely with total plant weight than did the height. The tuber weight fell off with a decrease in plant weight. This was to be expected, but the sharp reduction with some treatments was striking. Trebling the concentration of DDT halved the tuber weight. Plants treated with Dithane D-14 produced few and small tubers, and they were also small with the oil-solubilized DDT formulations and with HCCH.

TABLE 10.—Influence of various pesticides on the growth of potatoes in January in the greenhouse. Data given as percentage of the untreated check when that value equals 100. Sprayed 5 times at 6-day intervals.

Treatments	Weight of tops	Weight of 4th, 5th, and 6th leaves	Height of plants	Weight of tubers	Plant condition
No treatment	100	100	100	100	Normal.
Zerlate 2 100.	107	100	89	112	Normal.
DDT (50%) 2-100	107	107	96	112	Normal.
Cu 8 quinolinolate 1-100	104	83	87	112	Slightly yellow.
DDT (50%) 6-100	96	81	102	53	Leaves small.
Copper hydrate 3-100	96	90	87	107	Normal.
COC-S 4 100.	94	93	90	103	Normal.
Dithane + $ZnSO_4$ + lime 4-1½-100	84	55	91	41	Some leaf necrosis and marginal burn.
Deenol (25%) 2-100	80	62	103	48	Leaves small, stems weak.
Dithane D-14 4-100	75	36	103	17	Necrotic spots in leaves, many dead.
Bordeaux 8-8-100	72	80	83	52	Small leaves, some marginal burn.
JP 70 1-100	72	65	100	43	Leaves small, stems weak, slight chlorosis.
HCCH (6%) 2-100	67	63	65	39	Chlorosis, stunting, small tubers in leaf axils.

COMBINATION GROWTH AND TRANSPIRATION EFFECTS

During the summer of 1944 the extra large leaves and heavy vine growth of potatoes treated with DDT made it seem likely that this material was in some way stimulating growth. In an effort to determine the existence of any stimulating action, a series of potato plants were divided into nine groups with the plants in each group selected to be as similar to those in every other group as it was possible to determine by casual observation. When the plants were about 3 inches high they were sprayed for the first time with the formulas listed in table 11. Additional applications were made at weekly intervals. When the vines had reached approximately their maximum growth the amount of water lost from each group was determined at 2-day intervals for a period of 12 days. These data are recorded in table 11 as percentages of loss from untreated plants for the last 2 days of the 12-day period, and for the whole period.

TABLE 11.—Influence of various pesticides on rate of water loss, growth of tubers, and progress of vine collapse of Cobbler potatoes grown in the greenhouse from January 10 to April 10, 1945

Treatments	Water loss as percentage of check		Grams of tubers per plant	Weight of vines in grams 90 days after planting
	On last 2 days of 12-day period	During whole of 12-day period		
1. No treatment	100	100	602	510
2. Dithane + $ZnSO_4$ + lime 4-1½-100	99	103	360	630
3. Fermate 2-100	96	102	450	800
4. DDT (25%) 4-100	96	102	520	560
5. Zerlate + DDT 2-4-100	97	102	558	740
6. Dithane + $ZnSO_4$ + lime + DDT 4-1-½-4-100	102	100	275	730
7. Zerlate 2-100	93	97	590	910
8. Phygon 2-100	74	79	368	1180
9. Puratized (10%) 2-100	72	76	260	660

At the end of the transpiration study, the plants were photographed to show their general growth condition (fig. 4). At the end of 90 days (the normal outdoor maturity period for Cobblers) after planting, the average weights of the tops and of the tubers were determined for the group of six plants in each treatment. The average rate of water loss from the differently treated plants was similar for all treatments except Phygon and Puratized. Since the plants in these two groups were among the largest in size and leaf area (see fig. 4), it was evident that these two materials were depressing transpiration. On the other hand, the plants treated with Dithane, and Dithane plus zinc sulfate and lime, were losing as much water as any group, even though their leaf area had been considerably reduced by spray injury, indicating that this material was increasing transpiration above that of the untreated check plants.

No treated group of plants produced more tubers by weight than the check groups. Zerlate and Zerlate plus DDT approached them most closely, and Puratized produced the smallest crop. The plants treated with Puratized showed considerable chlorosis and produced comparatively small tubers. The large, rather elongated plants treated with Phygon (fig. 4) also failed to produce as many tubers as their size would lead one to expect. These Phygon-treated plants died more slowly than any others except those treated with Zerlate and Fermate (see last column of table 11). Some of the first to die were those that received DDT alone, or DDT with other materials, and the untreated checks.

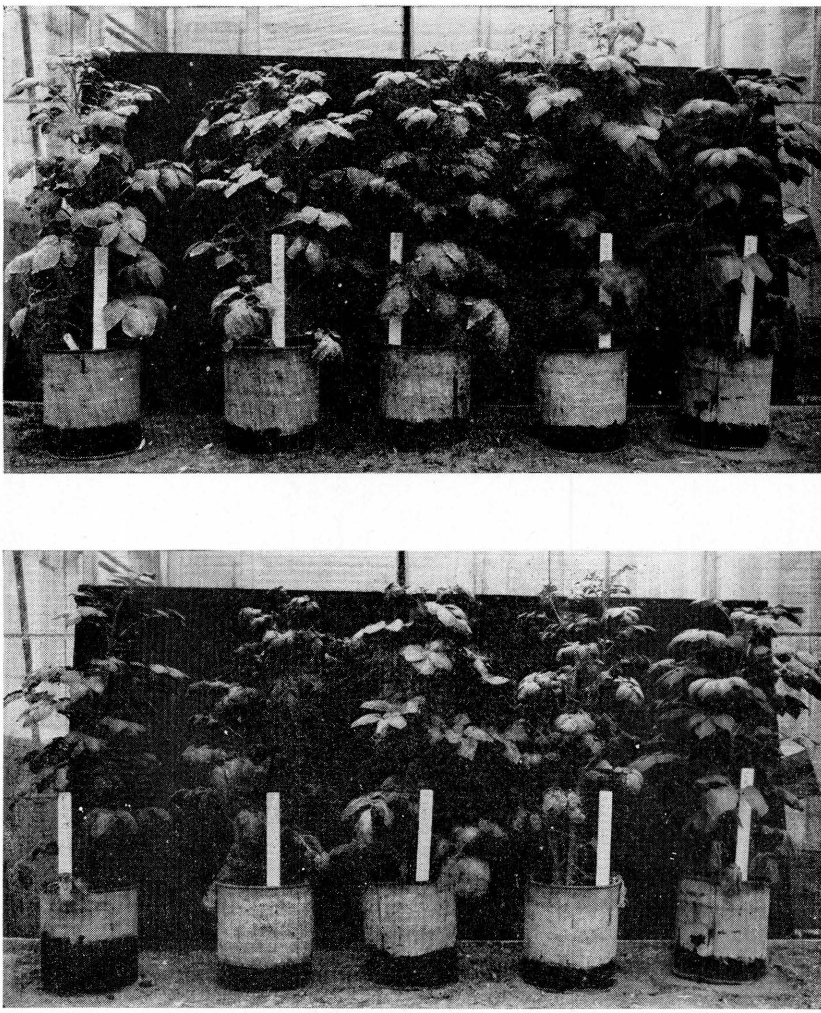

Fig. 4.—Relative growth of potatoes grown in the greenhouse and treated with various spray formulas (see table 12). The treatments from left to right in the upper section are: DDT, Zerlate + DDT, Zerlate, Phygon, and check; in the lower section they are: Fermate, Dithane, Puratized, Dithane + zinc sulfate and lime, and check.

EFFECT OF PESTICIDES ON TRANSPIRATION

Various fungicides, of which Bordeaux mixture is an example, are known to influence the rate of water loss from plants (3, 4). With this in mind it was decided to study the effect of some of the organic insecticides used in these experiments on transpiration rate of potatoes and tomatoes. To do this these two types of plants were grown in 1-gallon tinned cans until they reached a height of approximately 15 inches. The plants to be treated were then placed on a rotating table and their comparative transpirational capacity determined over a 4-day trial period. They were then grouped into sets of four plants each, each set having as near the same ability to lose water as it was possible to obtain. Each set was then treated with a particular formulation and their new rates of water loss determined for each day of a 4-day period. Some of the results obtained are shown in table 12, where the data are given as percentages of the loss from untreated check plants.

TABLE 12.—Influence of various insecticidal formulations on the rate of water loss from potatoes and tomatoes grown in the greenhouse in January and February 1946. Data given as percentage of loss from untreated check plants

Formulations	Loss from potatoes		Loss from tomatoes	
	On last day of a 4-day period	Totals for the 4-day period	On last day of a 4-day period	Totals for the 4-day period
No treatment	100	100	100	100
Rhothane (50%) 2-100	99	106	93	100
Methoxy (25%) 4-100	82	97	86	96
HCCH (6%) 5-100	80	96	73	88
DDT 2-100	100	112	73	82
DDT 6-100	86	99	64	80
JP 70 1½-100	73	94	63	85
Deenol 4-100	64	87	59	84

Most of these insecticidal materials were found to depress rather than accelerate transpiration. This effect was greater for tomatoes than potatoes, and the depression was probably connected with the fact that most of the materials under test were somewhat injurious to the leaf tissue. That in turn undoubtedly reduced the capacity of the leaf to lose water. That this explanation is valid was made more probable by the fact that transpiration became progressively less each successive day after the materials were applied to the foliage of the test plants. This gradual depression of the rate of water loss from the treated plants compared to that from untreated plants is illustrated in figures 5 and 6. Rhothane and Methoxy had the least effect on the rate of water loss from tomatoes, whereas Rhothane and DDT 2-100 were least active on potatoes. Deenol caused the greatest reduction on both types of plants.

The progressive depression of transpiration by materials of this type is further illustrated by the data of table 13. In the collection of these data the plants were weighed every 2 days for a period of 6 days after which they were set aside for 3 weeks to observe the development of visible growth reactions. Deenol again caused a marked depression in transpiration, but in this experiment HCCH reduced the rate of water loss even more. After 3 weeks the plants treated with Methoxy looked much like the untreated checks. Rhothane had caused only a mild chlorosis of some of the leaves that were young at the

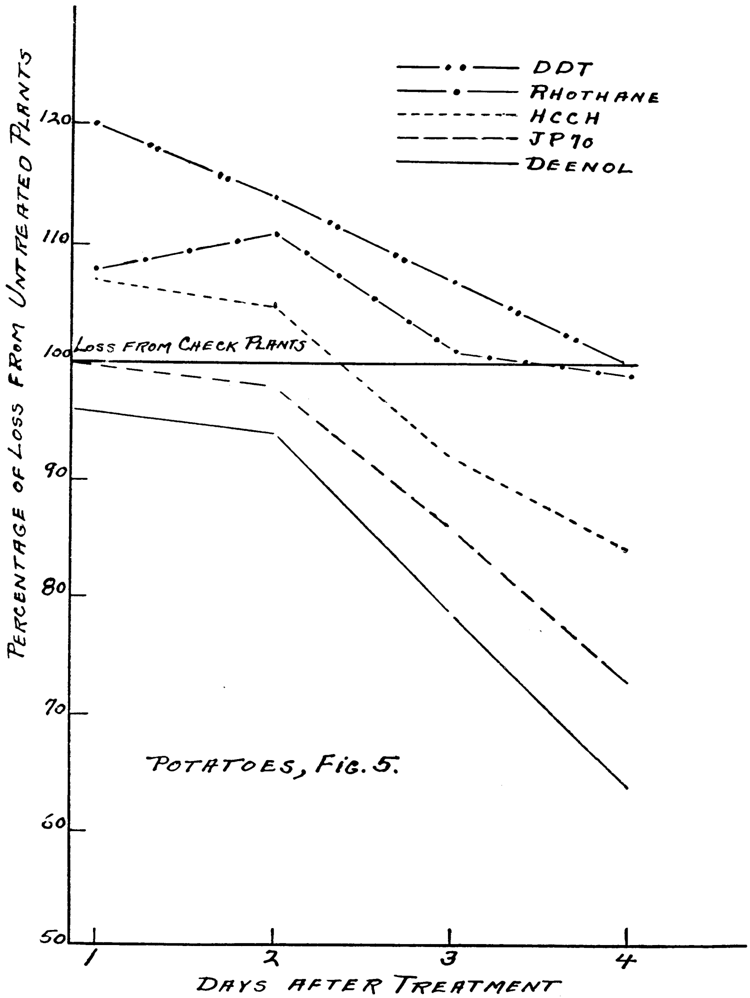

Fig. 5.—Progressive daily depression in transpiration from potato plants following the application of various organic insecticides.

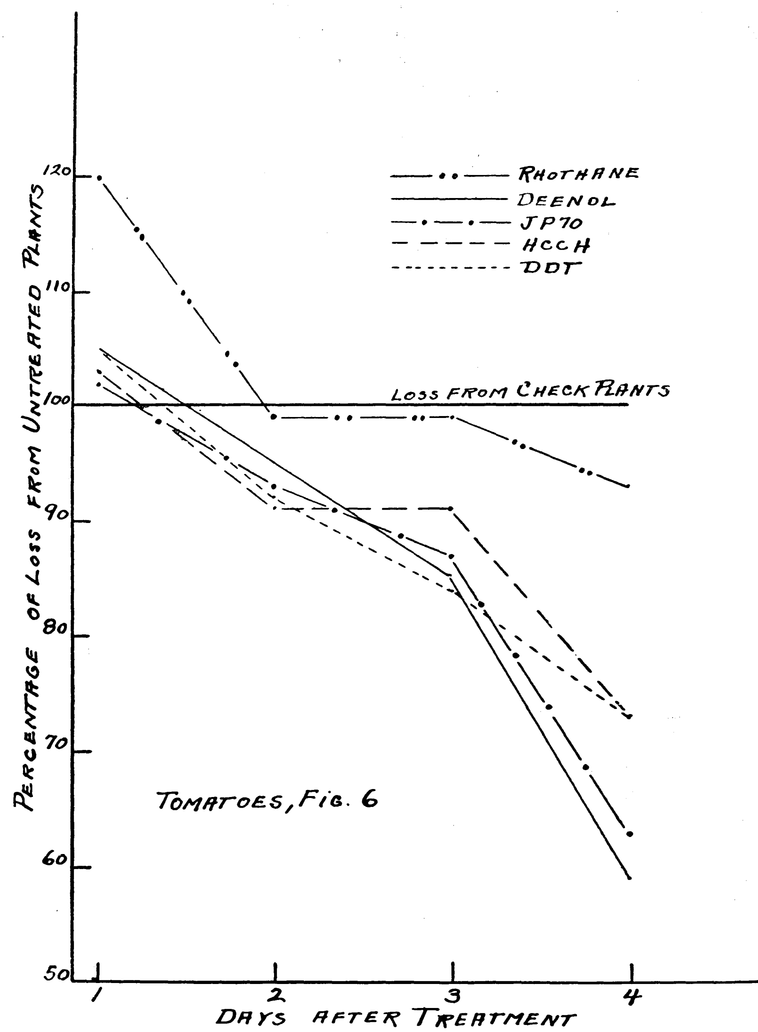

Fig. 6.—Progressive daily depression in transpiration from tomato plants following the application of various organic insecticides.

time the treatments were applied. Weak DDT (2-100) caused a mild mottling and chlorosis but these symptoms were much more severe from the stronger formula (6-100). Plants that had received the oil-solubilized DDT (JP 70 and Deenol) exhibited a comparatively severe chlorosis or yellowing of the leaves (somewhat spotted) and the plant wilted slightly at intervals. HCCH caused a severe malformation of the leaves which were small at time of treatment, and small areas of dead tissue appeared.

TABLE 13.—Influence of various insecticide formulations on the rate of water loss from greenhouse tomatoes. Notes on plant injury 3 weeks after sprays were applied are also given.

Formulations	Percentage of water loss from check plants during successive 2-day intervals after treatment				Notes on phytoxicity
	1 and 2	3 and 4	5 and 6	6-day total	
No treatment	100	100	100	100	Normal.
Methoxy (25%) 4-100	106	104	103	104	No symptoms of injury.
Rhothane (50%) 2-100	108	102	98	102	Mild chlorosis.
DDT (50%) 2-100	104	88	77	88	Mild mottling and chlorosis of the leaves.
JP 70 1½-100	101	86	76	86	Severe leaf chlorosis and some wilting.
DDT (50%) 6-100	102	84	71	84	Severe mottling and chlorosis of the leaves.
Deenol 4-100	97	82	67	80	Severe chlorosis and some wilting.
HCCH (20%) 5-100	91	73	49	68	Severe malformation, marginal burning, and necrosis.

The immediate influence of the fungicides used in the long-time growth experiment of table 11 on the transpiration of previously untreated potato and tomato plants is shown in table 14. Bordeaux and Dithane both caused some increase in transpiration with most of it occurring during the first 2 days after treatment, followed by a gradually decreasing effect. The remainder of the materials had little or no effect on the rate of water loss with the exception of Puratized. This material caused a decrease, again probably brought about by a killing of some of the leaf tissue that took that portion of the leaf out of the transpirational picture. One interesting response of the tomato plants sprayed with Puratized in this experiment was a drooping of the leaf petioles without visible wilting of the individual leaflets.

A considerable number of the newer fungicides were sprayed on potatoes on the first and fourth days of a 6-day test to compare their effect on transpiration in one and two applications. The data are given in table 15, where the losses were averaged for the first and second 3-day periods and then calculated as percentages of the loss from untreated plants. The effect of these materials (most of which were either slightly or not at all injurious) on water loss did not change with time, as was the case with the more injurious insecticides and fungicides. This also means that the additional load of spray material furnished by the second application had little or no effect in increasing the transpiration rate. Bordeaux, and Dithane plus zinc sulfate and lime, again increased transpiration somewhat; the effect of the fixed coppers was smaller; and most of the organic materials had but little effect on the rate of water loss.

TABLE 14.—Effect of various fungicides on the transpiration rate of potato and tomato on 4 successive days after treatment. Data given as percentage of loss from check plants when their value is taken as 100.

Treatments	Percentage of check loss on successive days after treatment					Symptoms of injury 2 weeks after treatment
	First	Second	Third	Fourth	Total	
Section A. Potatoes						
Check	100	100	100	100	100	Normal.
Bordeaux 8-8-100	147	143	138	111	133	Marginal burn on top leaves.
Dithane + $ZnSO_4$ + lime 4-1-½-100	138	133	138	120	132	Slight chlorosis of top leaves.
Dithane D-14 4-100	111	112	109	97	107	Severe necrosis, some lower leaves dead.
Zerlate 2-100	107	104	101	103	104	Normal.
COC-S 4-100	110	106	100	97	103	Normal.
Phygon 2-100	103	90	87	80	89	Slight chlorosis of lower leaves.
Puratized (10%) 2-100	95	93	87	71	85	Yellowing and dying of many lower leaves.
Section B. Tomatoes						
Check	100	100	100	100	100	Normal.
Dithane + $ZnSO_4$ + lime 4-1-½-100	121	115	111	110	113	Slight chlorosis.
Bordeaux 8-8-100	111	111	105	102	107	Slight marginal injury.
Phygon 2-100	111	108	103	103	106	Nearly normal.
Dithane D-14 4-100	102	100	98	101	101	Spot chlorosis. Slight marginal injury.
Zerlate 2-100	99	98	95	96	97	Normal.
COC-S 4-100	98	96	93	97	96	Normal.
Puratized (10%) 2-100	88	83	82	80	83	Severe wilting. Petioles turned down. Plants droop without wilting.

TABLE 15.—Transpirational response of potatoes when treated with various fungicidal materials. Values given represent percentage of loss from untreated checks when that equals 100. Sprayed on first and fourth days.

Treatments	Average water loss	
	First 3 days	Second 3 days
No treatment	100	100
Bordeaux 8-8-100	124	127
Dithane + $ZnSO_4$ + lime 4-1-½-100	116	117
COC-S 4-100	110	112
Copper hydrate 3½-100	109	112
Tribasic	107	110
Copper 8 quinolinolate 2-100	108	110
Manganese 8 quinolinolate 2-100	109	107
Zinc ethylene bis 2-100	105	105
Zerlate 2-100	100	106
Dithane Z 78, 2-100	101	105
Zn MBThiozole 2 100	102	101
Dithane D-14 4-100	98	92

The influence of a spray deposit builder known as Omilite (a polyethylene polysulfide latex) on transpiration, both when used alone and in combination with Bordeaux mixture and a fixed copper, was investigated in another experiment. The data are given in table 16. It was thought that the lattice formed as this material dried on the leaf might obstruct some of the stomata and thus reduce water loss but the transpiration rate of treated plants was no lower than for the untreated checks. The increase in transpiration commonly caused by Bordeaux was reduced slightly by the addition of Omilite. When it was added to COC-S there was no apparent effect in either increasing or decreasing the rate of water loss.

TABLE 16.—The influence of Omilite (polyethylene polysulfide latex) on the rate of water loss from potatoes.

Treatments	Average water loss when check equals 100	
	First 3 days	Second 3 days
No treatment	100	100
Bordeaux 8-8-100	117	115
Bordeaux + Omilite 8-8-2-100	107	105
Omilite 4-100	103	100
COC-S 4-100	105	107
COC-S + Latex 4-2-100	104	100

Late in the spring of 1946 another new fungicide in the form of a copper-zinc chromate was received and tested for its influence on the transpiration of tomato plants. When Bordeaux caused an average transpirational increase (during a 6-day period) over untreated plants of 10 percent, the increase caused by copper-zinc chromate was 6 percent. In the same experiment copper 8 quinolinolate gave an increase in transpiration of 4 percent, COC-S caused none, Phygon gave a decrease of 6 percent, and Puratized caused a drop of 22 percent below the untreated checks.

Since the addition of zinc sulfate and hydrated lime to Dithane D-14 had been observed to increase the transpiration rate of treated plants, it was decided to test the influence of additional amounts. With the rate of water loss from untreated check plants taken as 100 the losses from others treated with Dithane Z 78 (2-100), Dithane D-14 (4-100), D-14 plus $ZnSO_4$ and lime (4-1-½-100), D-14 plus $ZnSO_4$ and lime (4-2-1-100), and D-14 plus $ZnSO_4$ and lime (4-4-2-100) were 99, 95, 101, 104, and 106, respectively. This indicates that the mixture of zinc sulfate and lime (which could be called zinc Bordeaux), which by itself causes some increase in transpiration (5), carries this effect over to the mixture with liquid Dithane (D-14) where it offsets the injurious and thus transpiration-depression effect of the Dithane. The zinc-saturated material known as Dithane Z 78 apparently has little or no effect on transpiration.

Earlier in this discussion mention was made of the variable effect of different formulations of symmetrical hexachlorocyclohexane on the growth of cucumbers. In a test of their influence on the rate of water loss from tomato plants, it was found that all of them caused a decrease in transpiration. This depression varied from 8 to 18 percent for six different formulations. Rhothane and DDT in the same experiment caused respective depressions of 10 and 12 percent.

SUMMARY

Many of the new organic pesticides developed during the past few years were known to be phytotoxic, especially to certain kinds of vegetable plants. Since it was planned to use most of these later on field plots, it was decided to test them on plants grown in the greenhouse. These plants are usually more susceptible to injury from the application of pesticide materials than those growing outdoors.

In 1945 it was observed that not all varieties of cucumber were equally susceptible to injury by DDT; for instance, Ohio 31 was stunted to a much greater extent than National. DDT was found to cause more stunting when applied as a spray than as a dust. Also formulations prepared by different manufacturers were not equally phytotoxic. The degree of toxicity was found to vary with the diluent used in processing the DDT for use on plants.

When a series of organic insecticides were applied to cucumbers, Methoxy was found to be least toxic followed in the order of increasing toxicity by Rhothane, DDT, JP 70, Deenol, and HCCH. However, not all samples of HCCH were equally phytotoxic, and in later tests several formulations of HCCH were found to be less toxic to cucumbers than oil-solubilized DDT in the form of JP 70 or Deenol.

When DDT, prepared as a wettable powder containing 50 percent of the active ingredient, was applied to cucumbers in various concentrations it was found to be mildly phytotoxic, even at ¼ pound in 100 gallons. A further dilution to ⅛ pound (1/16 of active ingredient) in 100 gallons caused little or no injury.

The cucurbits were found to vary considerably in their susceptibility to injury by DDT, and to other organic insecticides such as Rhothane, Methoxy, HCCH, and the oil-solubilized forms of DDT. Some varieties of squash and cucumber were quite susceptible to DDT injury and watermelon and pumpkin were severely injured by HCCH and JP 70. Corn was injured to some extent by DDT at 4-100 and HCCH at 2-100.

Many of the insecticides which possibly might be used on cucumbers were found to cause stunting. Of these the synthetic organics were most injurious, whereas those prepared from plant sources were least toxic. The cryolites were intermediate in their phytotoxic effect on cucumbers. Most fungicides, including many of the new "organics" were only mildly phytotoxic, being less injurious than Bordeaux mixture.

When a large number of insecticides and fungicides were applied to tomato and potato plants, the fungicides, as a group, again were found to be less phytotoxic than the insecticides. Tomatoes were more susceptible to this type of injury than the potatoes. The oil-solubilized forms of DDT were highly phytotoxic to tomatoes in most instances and only slightly less so to potatoes. Among the organic insecticides, DDT and HCCH were more pyhtotoxic than Rhothane and Methoxy. Of the fungicides, Dithane D-14 was one of those most likely to cause injury, whereas Zerlate was one of the safest in this respect.

DDT seldom injured potatoes in these experiments but it usually caused a marked chlorosis on tomatoes, followed by stunting. Neither was DDT found to stimulate the growth of potatoes in an insect-free greenhouse environment. It did cause some depression in the transpiration rate when used at the rate of 6 pounds of 50 percent material in 100 gallons of water in several different tests. This slowing down of transpiration was quite marked with the oil-solubilized forms, as would be expected. All of the organic insecticides tested depressed transpiration of tomatoes and this was also true for potatoes but to a lesser degree.

This depression of the rate of water loss increased with time for the first few days after the materials were applied, probably due to the fact that more and more of the leaf tissue ceased to transpire normally as injury progressed.

Among the fungicides, Bordeaux mixture and Dithane D-14 plus zinc sulfate plus lime (a kind of Bordeaux) both increased transpiration for the first 2 or 3 days after application. Puratized and Phygon usually caused a decrease in the rate of water loss, and all others such as the fixed coppers and most of the new organics had little or no effect on transpiration.

After observing and recording the various physiological effects of the numerous pesticides used in this study the suggestion comes to mind that perhaps much of the lack of correlation that frequently exists between control efficiency and yield is related to the fact that phytotoxicity can offset, or even overbalance, the beneficial effects of disease and insect control. When this happens, a pesticide that offers the best balance between control and safety (lack of injury), takes first place on the basis of yield. This is frequently illustrated in comparative tests of the fixed coppers and Bordeaux mixture where plots treated with the latter often fail to yield as well as those that received a fixed copper, although foliage scores show more disease to be present in the latter.

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